COMBINING A MONOSTATIC SODAR WITH A RADAR WIND PROFILER AND RASS IN A POWER PLANT POLLUTION STUDY

Gennaro H. Crescenti[1] and Brian D. Templeman[1]
Atmospheric Sciences Modeling Division
Air Resources Laboratory
National Oceanic and Atmospheric Administration
Research Triangle Park, North Carolina 27711

John E. Gaynor
Environmental Technology Laboratory
National Oceanic and Atmospheric Administration
325 Broadway
Boulder, Colorado 80303

Abstract

A single-beam monostatic sodar, radar wind profiler, radio acoustic sounding system (RASS), and in situ sensors mounted on a 100-m tower were used to acquire meteorological data in the vicinity of a coal burning power plant in a northern Thailand valley. These data were used to examine the atmospheric processes that are responsible for fumigation of high concentrations of sulfur dioxide to the surface on a near daily basis during the cool season.

1. Introduction

High concentrations of sulfur dioxide (SO_2) are commonly observed during the cool season (November to February) in the vicinity of a coal burning power plant located in a northern Thailand valley. These high pollution fumigation events occur almost on a daily basis, usually lasting for several hours between late morning and early afternoon. One-hour average SO_2 concentrations are commonly observed in the range of 1000 to 2000 : g m^{-3}. As a result, an increase in the number of health complaints have been observed by local clinics during this time of year.

A field study was conducted during the winter of 1993/94 to investigate the atmospheric processes which lead to SO_2 fumigation. Data were acquired from a single-beam monostatic sodar, radar wind profiler, radio acoustic sounding system (RASS), and in situ sensors mounted on a 100-m tower in the vicinity of the power plant. A typical high pollution fumigation event is presented in this paper.

2. Description of the Problem

The power plant is located in the Mae Moh Valley about 25 km east of the Changwat Lampang Province in northern Thailand. The valley is about 15 to 20 km wide, 50 km long, and is aligned from northeast to southwest (Fig. 1). The valley floor is relatively flat with an average elevation between 320 and 360 m above sea level (asl). Two ridges parallel the valley on either side.

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[1]On assignment to the Atmospheric Research and Exposure Assessment Laboratory, U. S. Environmental Protection Agency.

To the northwest, the hills average 700 m asl; to the southeast, 900 m asl. To the northeast, the valley is also enclosed by hilly terrain. To the southwest, the valley opens to the Changwat Lampang Province. The valley is sparsely populated, with the largest concentration of people living in several small villages south of the power plant which coincide with agricultural activities (rice, sugar cane).

The coal burning power plant was constructed in several phases over the last two decades in the center of the valley to take advantage of a nearby lignite reservoir. A total of eleven separate power generators in two separate facilities produce approximately 2.025 GW of power, supplying about a quarter of Thailand's electricity. The three stacks of the first facility (Units 1, 2, and 3) are 85 m high, while the seven stacks of second facility (Units 4 through 11) are 150 m high. The base of all eleven stacks are 320 m asl. While electrostatic precipatators are present in each unit to remove particulates, there are no pollution controls (i.e., scrubbers) to remove SO_2. Since there are no other major industrial activities in the Mae Moh Valley, the power plant is the source for nearly all of the observed SO_2 (Saengbangpla et al., 1981; 1982).

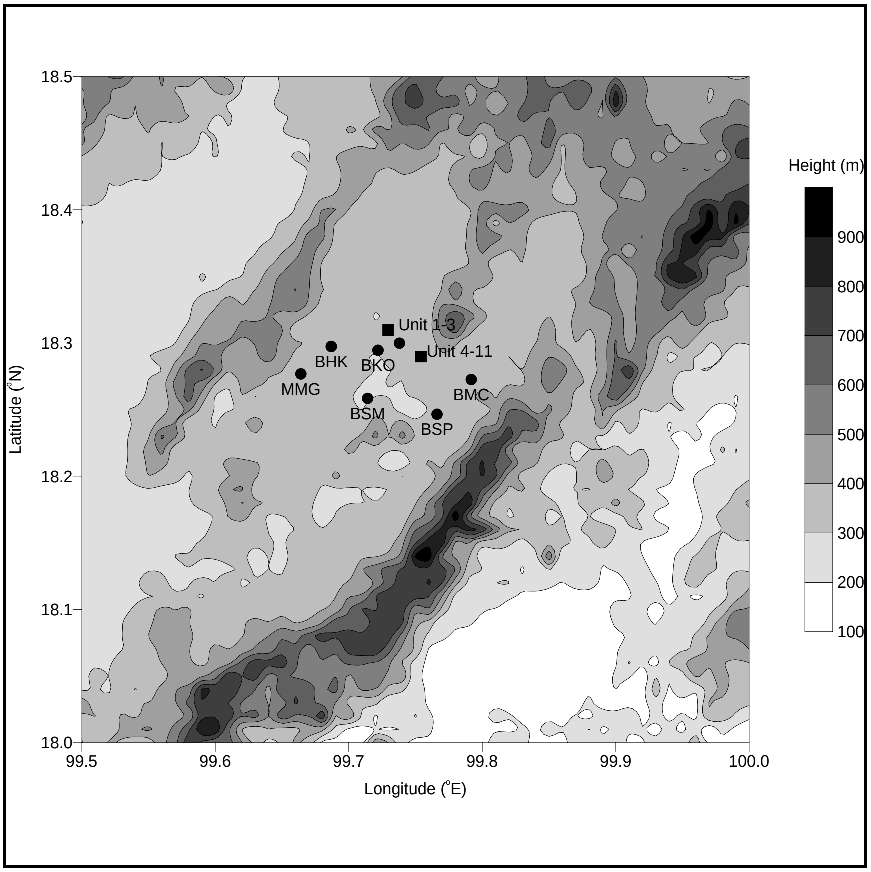

Figure 1 Mae Moh Valley. Power plant is represented as the two squares. SO_2 monitoring stations are depicted by the circles. The unlabeled circle between the two squares is the 100 m tower.

The number of health complaints have increased during the cool season when high concentrations of SO_2 have been observed at numerous monitoring stations in the vicinity of the power plant. These high pollution fumigation events, which occur on almost on a daily basis, last for no more than several hours, usually starting in the late morning and ending by mid afternoon.

3. Instruments and Measurements

Meteorological and SO_2 data were acquired during an intensive field study from early December 1993 to mid February 1994. A 2 KHz single-beam monostatic sodar was located about 3 km to the west of the power plant near Ban Ko-Or (BKO). The sodar continuously recorded the thermal structure of the atmosphere on facsimile charts from the surface up to 700 m. A 915 MHz radar wind profiler and RASS were collocated with the sodar. One-hour average wind profiles were acquired from 140 m up to a height of about 2500 m over 60 m intervals. One-hour average virtual air temperature profiles were collected in the range of 125 to 1300 m over 60 m intervals. In-situ meteorological measurements were made from a 100-m tower located between the two power generating facilities. The measurements included horizontal and vertical wind velocities at 10, 50, and 100 m; air temperature and relative humidity at 2, 10, 50, and 100 m; and solar radiation. In addition, turbulent flux measurements were acquired by a sonic anemometer at 10 m. These data were acquired as 15 minute averages. Continuous SO_2 measurements were made at seven sites 1 to 8 km from the power plant and were recorded as 10 minute averages. The locations of these stations may are given in Figure 1.

4. Analysis

Figure 2 shows SO_2 concentrations for three sites for 1 January 1994. The highest concentration was observed at the 100-m tower in between Units 1-3 and Units 4-11. The highest one-hour SO_2 average reached 1378 :g m^{-3}. Monitoring stations located to the west and east of the power plant, Ban Huai Khing (BHK) and Ban Mae Chang (BMC), respectively, had one hour average concentrations in excess of 1200 :g m^{-3}. However, the time in which SO_2 fumigation begins at each monitoring site is not always the same for each fumigation event. In addition, not all of the monitoring sites observe fumigation of SO_2. In fact, very little SO_2 was observed at Ban Sop Moh (BSM) and Ban Sop Pad (BSP), and no discernable elevation of SO_2 concentrations was seen at the Mae Moh Government Center (MMG) for this particular day.

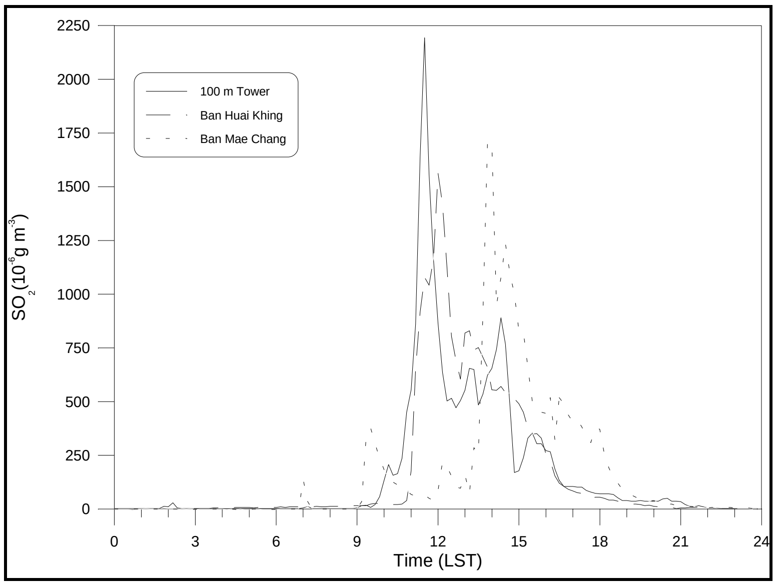

Figure 2 SO_2 concentrations observed on 1 January 1994 at the 100 m tower, Ban Huai Khing, and Ban Mae Chang.

Analysis of the large scale synoptic weather features show the extension of the Asian winter anticyclone over northern Thailand. During the high pollution fumigation events, the high pressure system is displaced southwards. The geopotential height field at 700 and 500 hPa between Bangkok in southern Thailand and Ching Mai in northern Thailand is relatively flat. Strong subsidence is observed over the valley from data acquired by the radar wind profiler. Analysis of the vertical wind velocity and scattering parameter (c_n^2) for 1 January 1994 show a clear delineation of the top of the daytime mixed layer at 1500 m for the entire day. For most days when SO_2 is not observed at the surface, the daytime mixed layer height is generally greater than 2000 m.

Wind profiles from the radar show light and variable flow in the first several hundred meters during the predawn hours (Fig. 3). This is typical for many of the high pollution fumigation events. The early morning winds are generally less than 1 m s^{-1} and are scattered in a range of directions, namely from the west, north, and east. This is probably a result of the interaction of several drainage flows from the various ridges surrounding the valley. Since the radar site was situated in the center of the valley near the power plant, it is difficult to establish a predominant early morning drainage flow pattern. During non pollution days, the wind profile in the first 1000 m tends to be more organized and higher in velocity.

A composite temperature profile was constructed by combining data taken at the 100-m tower and from the RASS (Fig. 4). Strong radiational cooling during the evening and predawn hours is responsible for creating a surface inversion of 10 ^{o}C to 400 m just prior to sunrise (0600 LST).

Strong solar heating is observed shortly after sunrise, with a maximum value of 700 W m^{-2} at 1300 LST. The sensible heat flux at 10 m is also strong reaching a maximum of 225 W m^{-2} at the same time as maximum solar heating. By noon, the first kilometer becomes well mixed. The highest surface temperatures are observed from mid to late afternoon.

The monostatic sodar shows the presence of several shallow inversion layers before sunrise (Fig. 5). The highest is approximately 300 to 350 m above the surface. Another is located at 175 m. This image provides evidence for a mechanism to trap some, if not all, the stack-emitted SO_2 within these layers during the early morning hours. Since winds in the first several hundred meters are generally light, the SO_2 is likely being pooled in the immediate vicinity of the power plant. The exact placement of the SO_2 plume is probably dependent upon the valley winds pushing it one way or another. Figure 6 shows the rapid growth of the convective boundary layer during the late morning. It is at this time that the nocturnal inversion has been eroded by surface heating and the pooled SO_2 is fumigated to the surface by turbulent convection. From 1100 to 1200 LST, the extent of the vertical convection quickly increases from 350 m to over 600 m. This is the same time period when dramatic increases of SO_2 are observed at several monitoring sites at the surface. The time it takes for the SO_2 plume to be fumigated to the surface may be estimated by using the convective vertical velocity scale (Stull, 1988)

$$w_* = \left[\frac{g\ z_i}{\overline{\theta}_v}\ \overline{(w'\,\theta_v')}_s \right]^{1/3}$$

where g is the acceleration due to gravity (9.8 m s^{-2}), z_i is the mixed layer height, 2_v is the mean virtual air temperature of the mixed layer, and $(w'2_v')_s$ is the surface kinematic heat flux. Using data taken at 1100 LST on 1 January 1994, the convective velocity is approximately 1 m s^{-1}. Since the mixed layer height is estimated to be 350 to 400 m, then it would take about 5 minutes for fumigate the plume to the surface.

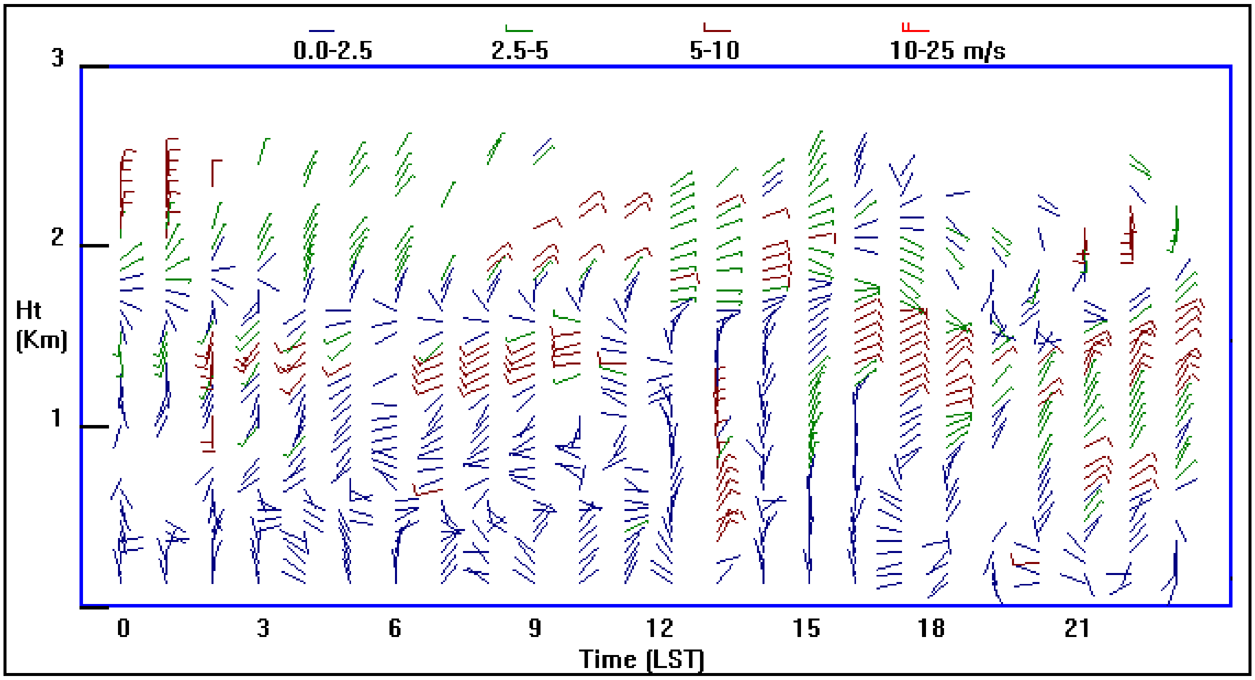

Figure 3 Wind profile data obtained by NOAA 915 MHz radar on 1 January 1994.

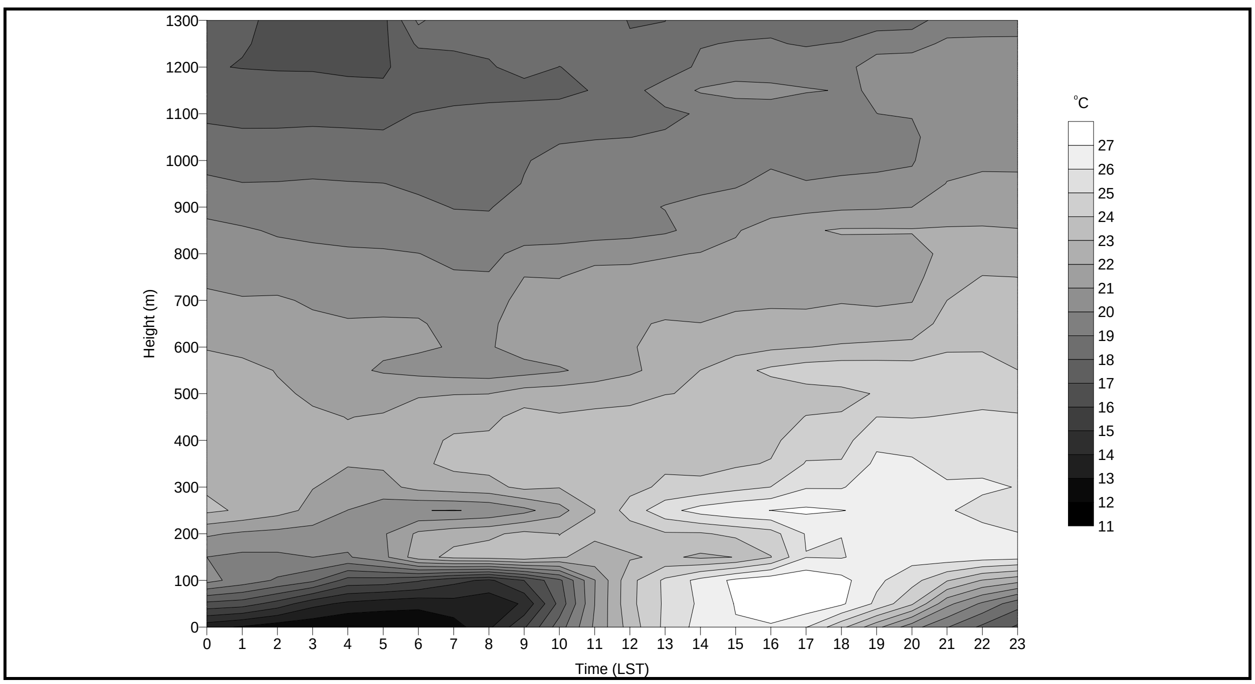

Figure 4 Temperature profile based on tower and RASS measurements for 1 January 1994.

5. Summary and Conclusions

Large scale subsidence, light and variable winds, a strong nocturnal surface inversion, and an elevated inversion just above plume height are the key ingredients for trapping SO_2 at several hundred meters above the Mae Moh Valley floor. Fumigation of SO_2 has been observed at surface monitoring stations when convective heating has eroded the inversion and convective mixing has reached the trapped plume. Synoptic scale meteorology controls the likelihood of fumigation, while meso- and microscales control the time of onset, concentrations, and placement of fumigation.

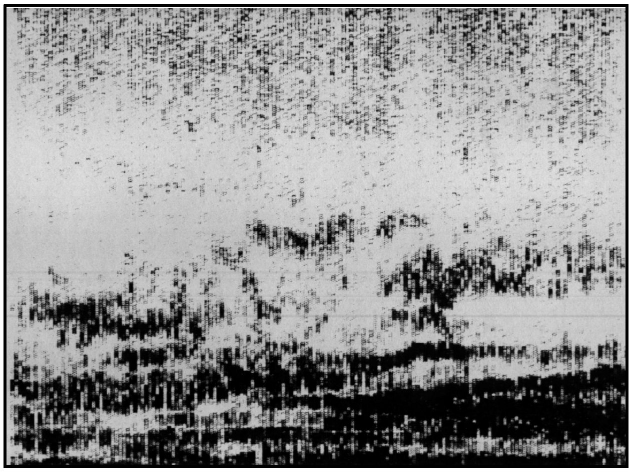

Figure 5 Monostatic sodar data for 1 January 1994. X axis is time (positive from left to right) from 0300 to 0400 LST. Y axis is height from 0 to 700 m.

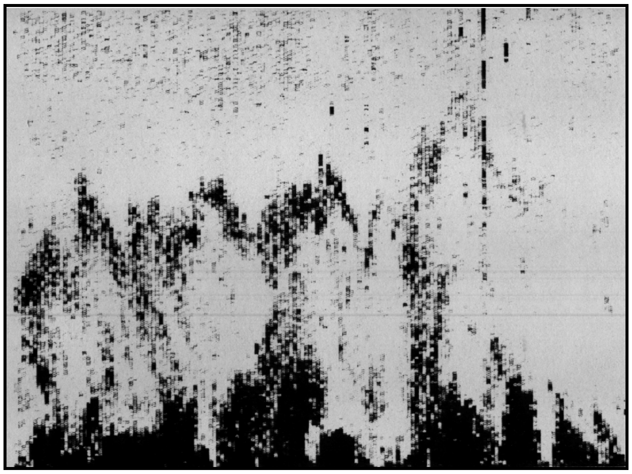

Figure 6 Same as Fig. 5. Time is from 1100 to 1200 LST.

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